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FLOW QUANTITIES IN RESIDENTIAL

WEEPING TILE SYSTEMS

- A CALCULATIONAL METHOD

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WEEPING TILE SYSTEMS

- A CALCULATIONAL METHOD

by

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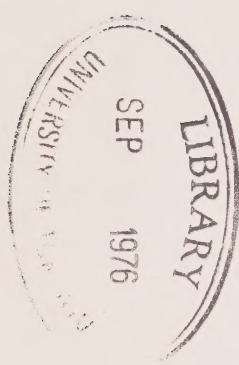
ABSTRACT

A calculational method is presented for determining
the flow quantities produced by the residential weeping
tile systems. Application of equations based on Darcy's law
and the continuity equation will allow theoretical calculations
of weeping tile flow quantities to be made for situations
where only soil conditions and prevailing hydrological
information is known.

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1.0   INTRODUCTION

The installation of weeping tiles for residential
property drainage has riased the question of what should be
done with the collected quantity of water. The possibilities
are:

1. connection to the sanitary sewer

2. connection to a storm sewer

3. proper grading with runoff away from the
    house

4. storage of excess wet weather flow

5. overflow treatment

6. diversion of roof leader.

To make a proper decision, the flow quantity per
subdivision must be estimated. The investigation of the problem
has been presented here on a per house basis. Because of
the inapplicability of previously collected experimental data
for use in a new drainage situation, it is necessary to calculate
the expected flow in the weeping tile by a theoretical analysis.
The combinations of techniques[1] used to characterize the flow
have sound theoretical and physical bases and have proven
to be correct in several experimental situations. [2, 3, 4]

Requirements for using the calculational procedures
are a thorough knowledge of the physiography and soil conditions
of the area, a proper perspective in the judgement of the
hydraulic situation, and knowledge of the technique used in
laying the weeping tile.

For characterization, the weeping tile flow can be divided into several phenomenological situations.[1]

1. Infiltration into the soil at the start of a rainfall

    (a) The initial infiltration is characterized by a time lag, from the start of the rainfall to the initial observation of flow in the tile.

    (b) When the infiltration water reaches the water table, it may be necessary for the water table to rise to the weeping tile level before flow will begin. Thus, the time lag is also dependent on the location of the water table level.

    (c) For the occurrence of a short rainfall the water table may not rise sufficiently to reach the weeping tile and no flow will be observed.

2. Flow to the weeping tile

    (a) The flow to the weeping tile is calculated on the basis of the effective land area under the influence of the drain and the maximum rise of the water table height if no drainage were to occur.

    (b) The variation in drain flow follows the variation in the rainfall intensity but with a time delay corresponding to the infiltration time.

3. Decrease in weeping tile flow after rain has ceased

    (a) Once the rainfall has stopped, the tile flow continues but decreases in an exponential manner over a period of time until the flow eventually ceases.

    (b) The time required for the flow to cease after the rainfall has stopped is dependent on the depth

of the impermeable barrier below the tile level.
The time interval for the flow to cease decreases
as the depth between the impermeable boundary
and the weeping tile increases.

The example calculation in Section 4.5 shows the
roof flow quantity to be 43% of the total flow. On this basis,
the roof runoff contribution may be greatly reduced on larger
lots where the drain pipe from the eavestrough may be extended
beyond the calculated distance of weeping tile area of influence.

In addition, it may be possible to reduce the weeping
tile flow further by proper grading of the lots so that runoff
flow is away from the houses.

2.0 REPLENISHMENT OF THE WATER TABLE

The rate at which water moves into the water-table
zone is determined by the infiltration rate through the soil.
Overall, the rate at which the water replenishes the water
table zone is not the same as the rate of rainfall. The
factors which influence the replenishment rate are:

1. Soil moisture at the time of the rain storm.
    Before water can percolate down to the water
    table zone the soil above the water table must
    become saturated.
    The moisture content of the soil at the start
    of precipitation determines the amount of, and
    time at which, the water percolates into the ground-
    water zone.

2. Interception losses
    Some of the water which falls is intercepted by the
    vegetation and never reaches the soil surface.
    The amount of interception depends on the grass,
    presence of shrubs, flower gardens, and trees.
    The amount of interception is also dependent on the
    rate of precipitation.

3. Deep Seepage
    While precipitation is occurring there may be
    seepage through layers lying beneath the drain
    level. This deep seepage must be subtracted from
    the rainfall to obtain the amount of tile flow.

4. Surface runoff

    The amount of surface runoff will depend
    on the soil infiltration rate, the slope
    of the land surface, the rate of precipitation,
    and the soil moisture content.

5. Evapotranspiration

    Some of the water which falls will be
    evaporated from the soil surface and some will
    be transpired by the vegetation.

In general the replenishment rate may be expressed
by

$$Q_{rep} = Q_{precip} - \left(Q_{inter} + Q_{deep} + Q_r + Q_e \right)$$

where Q_{rep} = the replenishment rate

Q_{precip} = the precipitation rate

Q_{inter} = the interception rate

Q_{deep} = the deep seepage rate

Q_r = the runoff rate

Q_e = the evapotranspiration rate.

Estimates of peak runoff rates may be made using
the 'rational method'[5]; in its simplest form,

$$Q_r = CiA$$

where Q_r is the design peak runoff rate,
cfs

C is the runoff coefficient

i is the average rainfall intensity
in inches per hour for the design
reoccurrence interval and for the

duration time equal to the
time of concentration

A   is the drainage area in acres.

3.0 WEEPING TILE DESIGN EQUATIONS

The following is a summary of the equation required to estimate weeping tile flow quantities. The symbols are listed in the nomenclature section.

1. Infiltration - the initial process of water seepage through dry or drained soil to reach the water table.

    Flow quantity:

    $$Q = k_T \cdot A \cdot \frac{h_T + y}{y} \qquad \ldots\ldots\ldots(1)$$

    Time to reach the water table level:

    $$t = \frac{nsh_T}{k_T} \left[\frac{y}{h_T} - \ln\left(1 + \frac{y}{h_T} \right) \right] \ldots\ldots(2)$$

2. Weeping Tile Drainage - the quantity flowing through the drain as a function of the average rainfall intensity.

    $$Q = RL$$

    Condition 1: Drain located at water table (Fig.1)

    $$h_L^2 - H^2 = \frac{R}{k} \left[L\,(L-2\alpha_1 H) \right] \qquad \ldots\ldots(3)$$

    $$\text{where } \alpha_1 = \frac{1}{\pi} \ln \left[2\left(\cosh \frac{\pi d}{H} - 1 \right) \right] \quad \ldots\ldots(4)$$

    Condition 2: Drain located below the water table (Fig. 2)

    $$h_L^2 - H^2 = \frac{R}{k} \left[L\,(L - 2\alpha_2 H) \right] \qquad \ldots\ldots(5)$$
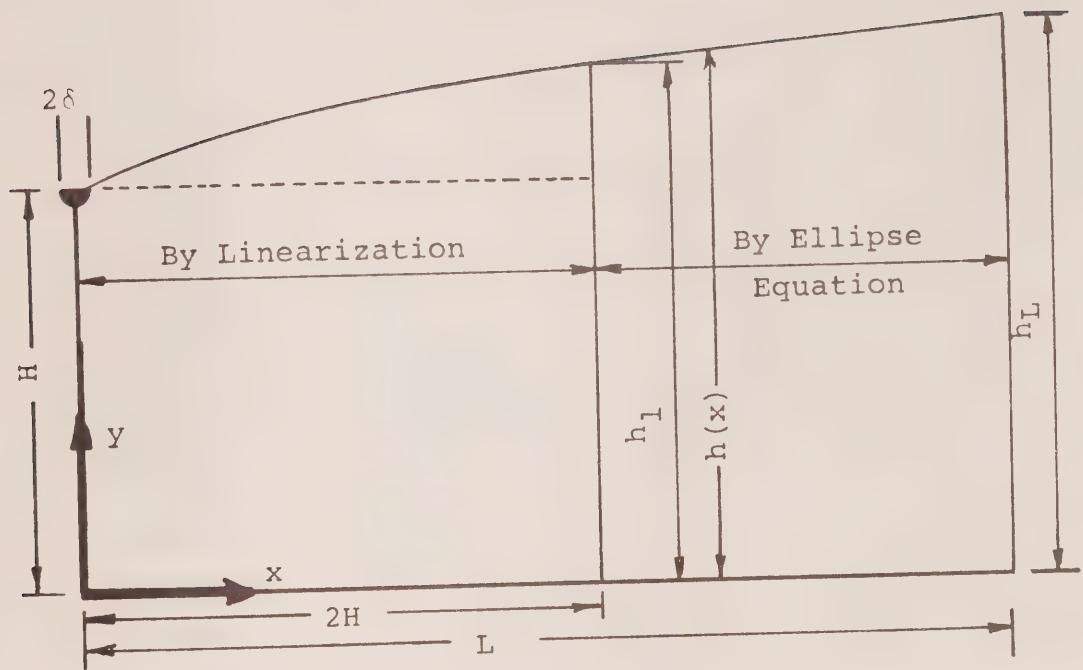
Figure 1. Drain Located at Water Table[6]
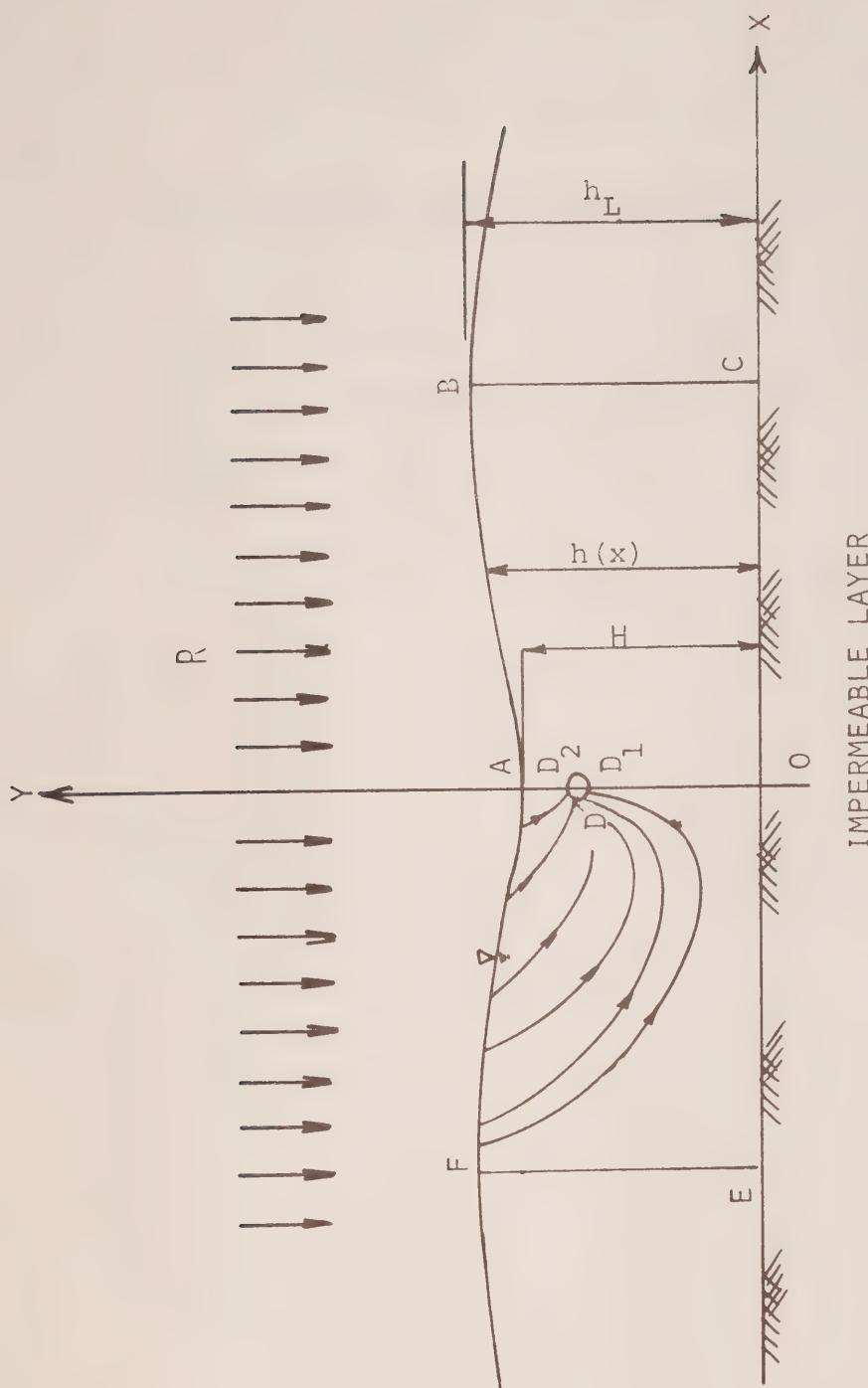
Figure 2. Drain Located Below Water Table.

$$\text{where } \alpha_2 = \frac{1}{\pi} \ln \left[2 \left(1 + \cos \frac{\pi y_0}{H}\right) \right] \qquad \ldots (6)$$

3. Time for Drainage after Precipitation Ceases (Fig. 3)

The time for flow to cease after precipitation stops is obtained from the dimensionless curve of Figure 4. The volume of water removed at any time during the drainage may be obtained from Figure 5.
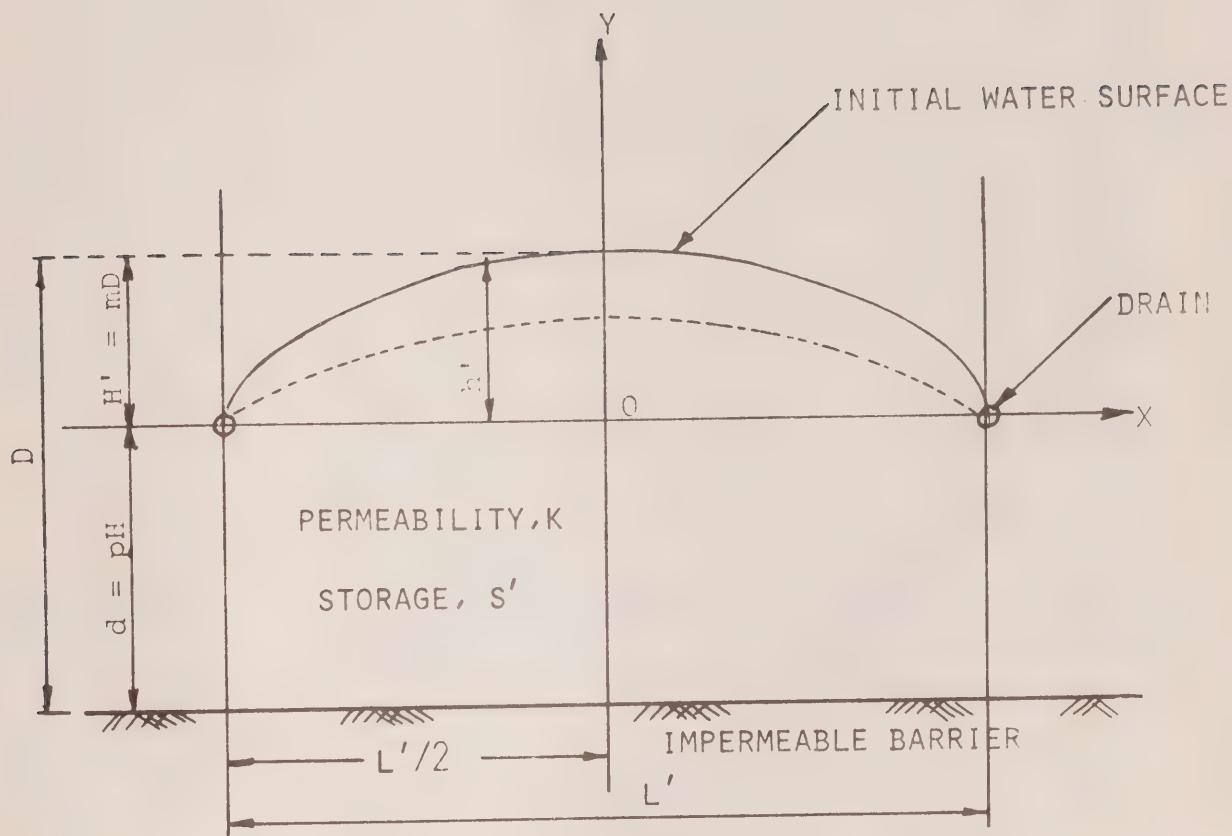
Figure 3.   Conditions for Unsteady State
Drainage Model.[7]

Figure 4. Dimensionless curves of rate of discharge, q, versus time, t, for parallel drains at various distances above an impermeable barrier. (8)

Figure 5. Dimensionless curves of volume of water removed, V, versus time, t, for parallel drains at various distances above an impermeable barrier. [8]
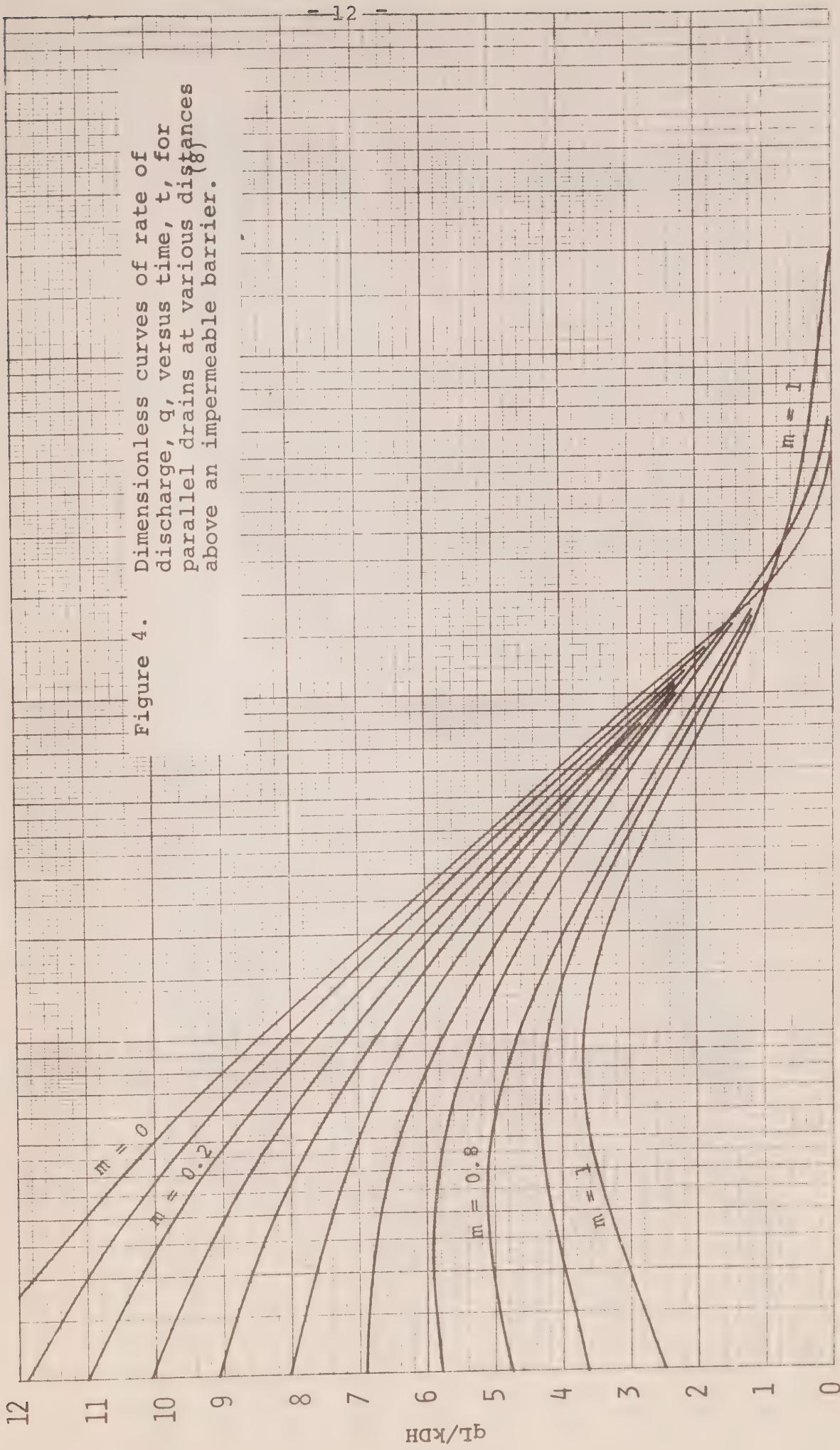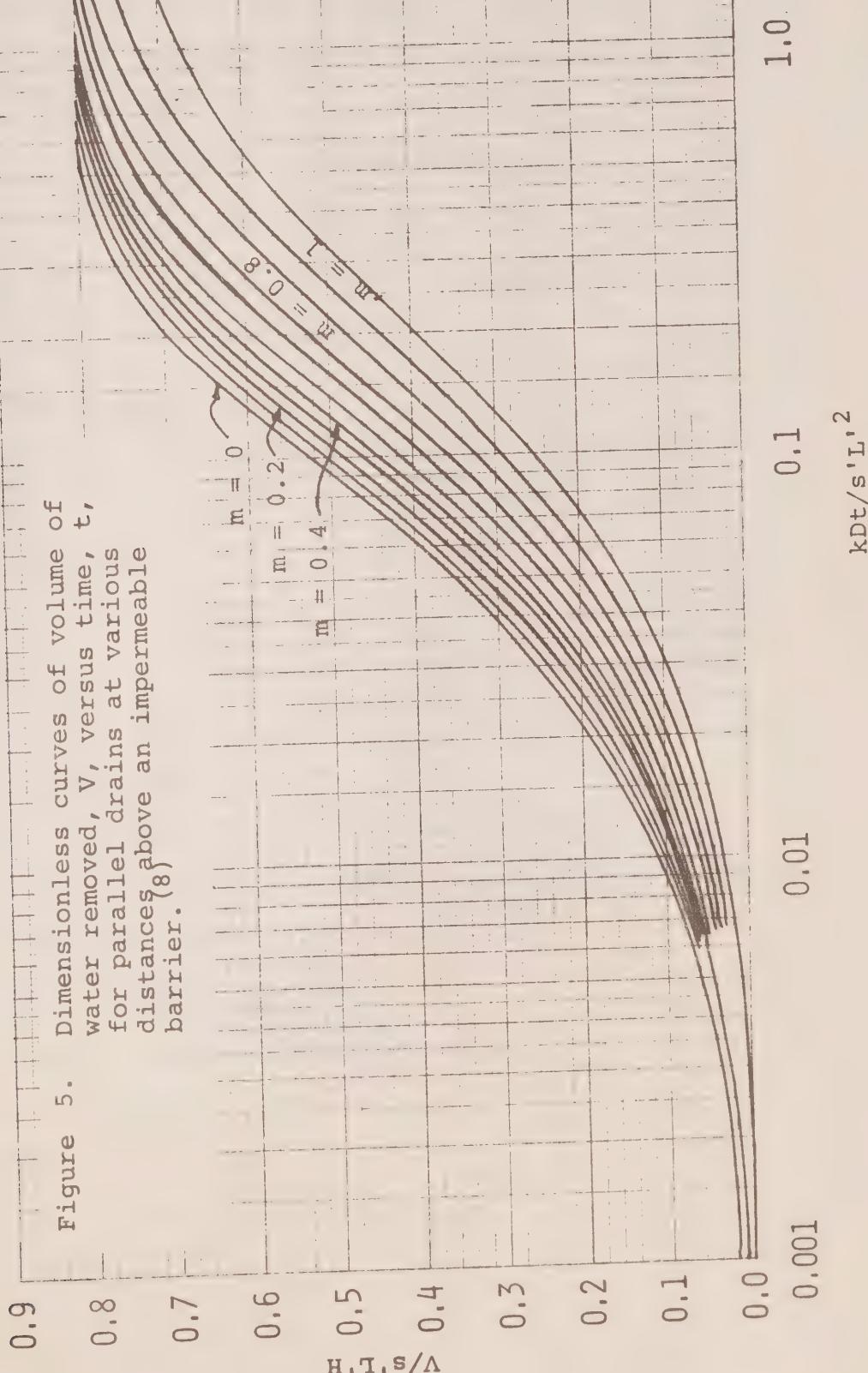
4.0   SAMPLE CALCULATION OF WEEPING TILE FLOW

To illustrate the above technique for calculating conditions for weeping tile flow, an example is worked out for a typical house and surrounding property. Figure 6 shows the layout of a house in Niagara Falls from which experimental data has been obtained[9].

The weeping tile is 10.2 cm(4") clay tile and the backfill is 0.95 cm (3/8") crushed stone. The effective roof rain area is 105.9 m^2 (1140 ft^2). The total length of the weeping tile is 44.65 m (146.5 ft).

4.1   Hypothetical Rainfall

Assume for calculational purposes a hypothetical rainfall of 2.54 cm (1.0 inch) with a duration of 6.5 hrs and a maximum intensity of 0.76 cm/hr (0.3 in/hr) occurring after 2 hours. An intensity - time curve for this rainfall is shown in Figure 7. The average intensity is taken to be 0.3908 cm/hr (0.1538 in/hr).

4.2   Soil Conditions

Using the experimental results from the previous weeping tile study in addition to other information [9,10], the assumed soil properties are listed in Table 1.

Table 1.   Soil Properties

Saturation coefficient s = 0.25

Storage coefficient s'   = 0.08

Porosity, n = 0.25

k = 0.174 cm/min (0.0685 in/min)
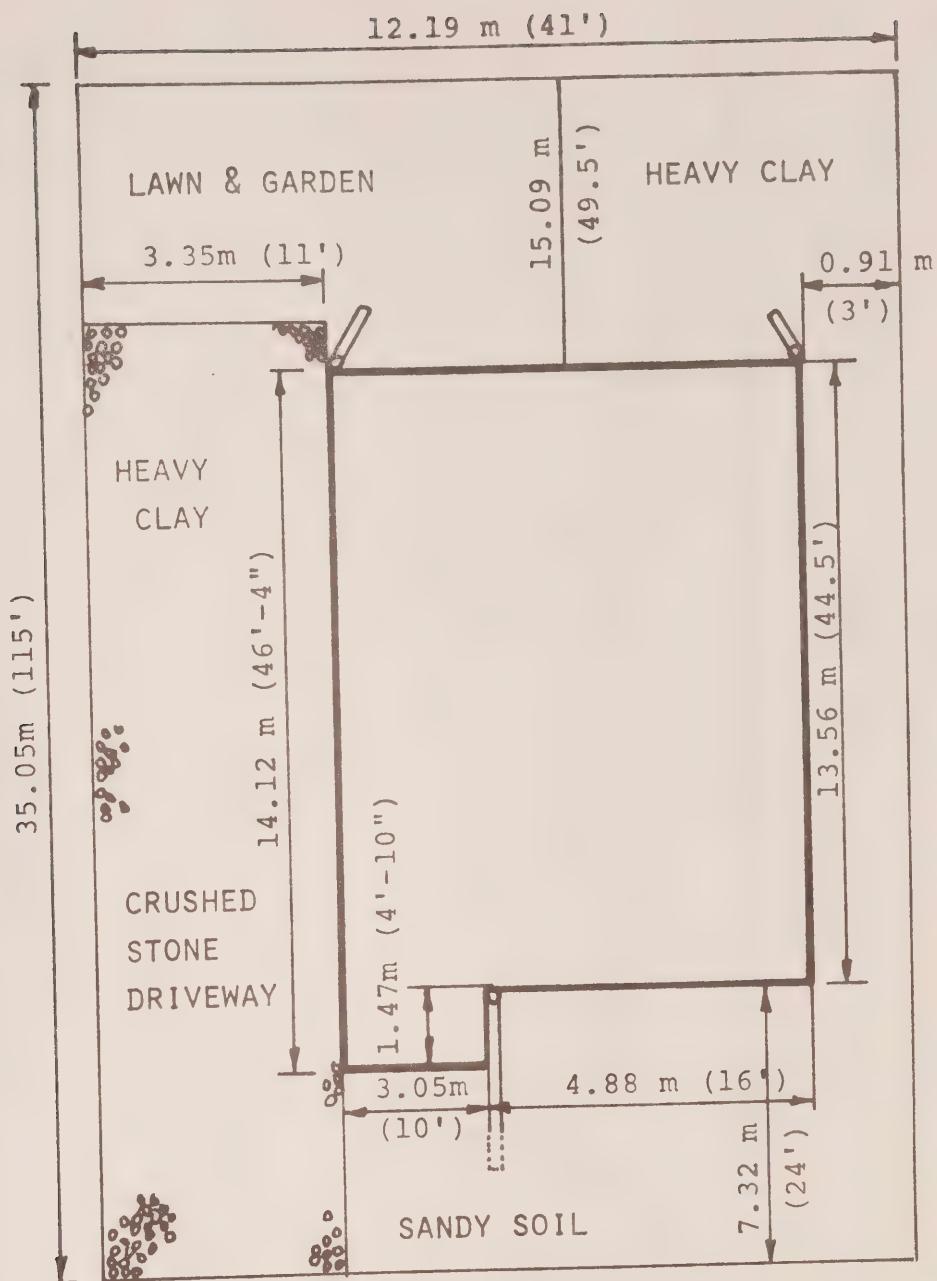
Figure 6.   Niagara Falls House and Surrounding
             Property.
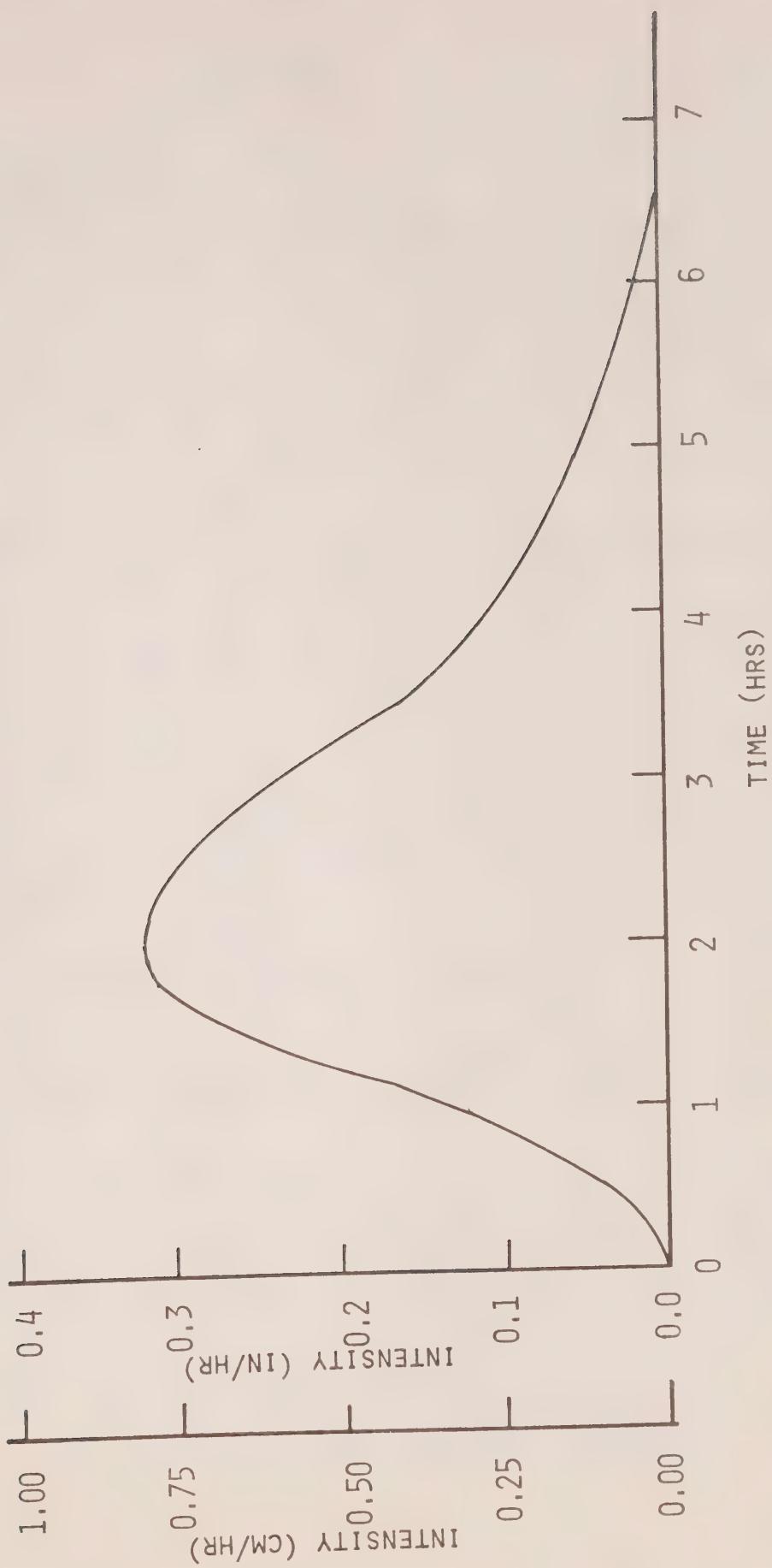
Figure 7. Rainfall Intensity Versus Time.

Total Rainfall = 2.54 cm (1 in)
Duration   = 6.5 hr

Maximum Intensity = 0.76 cm/hr
(~0.3 in/hr) at 2 hrs.

4.3 Infiltration Time

To determine the time for the rain to produce a flow in the weeping tile, it is necessary to know the distance to the impermeable barrier. For this example, we will assume that the impermeable barrier is located just below the bottom periphery of the weeping tile as shown in Figure 8, and the water table is at this level.

Assuming the following conditions for infiltrations:

$$y = 182.8 \text{ cm } (\quad 6 \text{ ft})$$

$$h_T = 88.9 \text{ cm } (\quad 35 \text{ in})$$

$$n = 0.25$$

$$s = 0.25$$

$$k_T = k = 0.1741 \text{ cm/min } (0.0685 \text{ in/min})$$

Using equation (2)

$$t = \frac{nsh_T}{k_T} \cdot \left[\frac{y}{h_T} - \left(\ln \ 1 + \frac{y}{h_T} \right) \right]$$

$$= \frac{0.25 \times 0.25 \times 88.90}{0.1741} \left[\frac{187.88}{88.9} - \ln \left(1 + \frac{182.88}{88.9} \right) \right]$$

$$\therefore \quad t = 29.9 \ \text{min}$$

Therefore 30 minutes will elapse before the rain will reach the weeping tile. If both the impermeable barrier and the water table are farther below the weeping tile level, the time lag before flow will begin will be longer, due to the extra infiltration distance and the time required for the free surface to reach the tile.

Figure   8.   Dimensions for Example Calculation.

GROUND SURFACE

182.9cm (6')

STONE FILL

WATER TABLE LEVEL

IMPERMEABLE BARRIER

10.2cm (4") WEEPING TILE
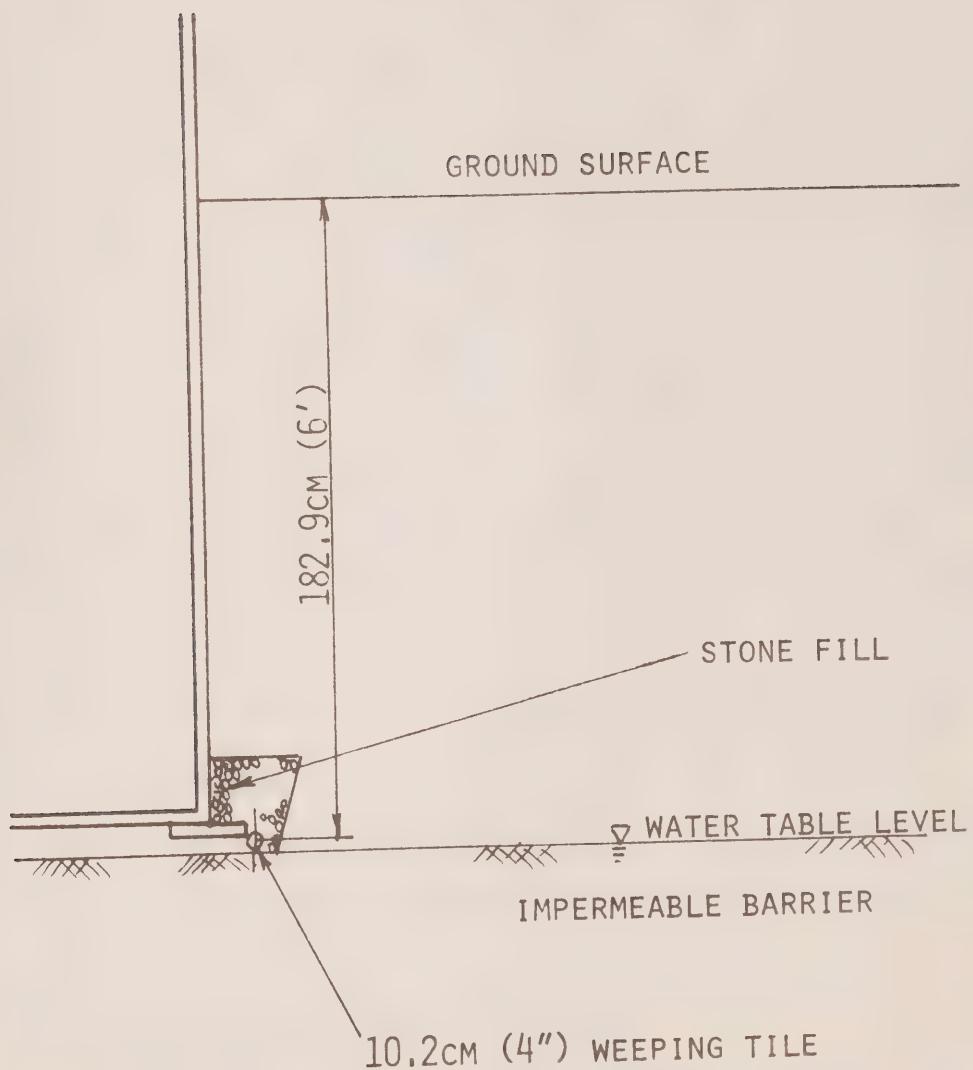
For example, if y = 192.88 cm (75.94 in) with the
other conditions the same, the infiltration time to the free
surface will be 32.43 min for an extra 10 cm (3.94 in).
In addition, the water must rise to the weeping tile level
through this distance of 10 cm.

For a rise of 10 cm, the quantity of rain required
is

$$V_{rain} = ns\Delta h$$

> where V_{rain} is the volume of rain
> required, cm/cm^2, Δh is the distance
> of rise, cm.

$$\therefore \quad V_{rain} = 0.25 \times 0.25 \times 10$$
$$= 0.625 \text{ cm } (0.246 \text{ in})$$

Thus, 0.625 cm of rain are required to raise the water
table 10 cm. Using Figure 7, the area under the intensity-
time curve gives the cumulative quantity of precipitation up to
time, t. For the required quantity of 0.625, the area under the
curve up to 1.8 hrs (108.75 min) gives the value of 0.625 cm
(approximately). Therefore, the minimum total time before
weeping tile flow begins is 108.75 min or an increase of 76.32
min as compared to the situation when the water table level is
at the tile level.

4.4 Effective Weeping Tile Field Area

The horizontal distance perpendicular from the tile
which is effective for drainage is calculated from equation
(3). The maximum height of rise of the water table is calculated
from the total rainfall using the relation

$$h_L = h_{rain}/ns$$

where h_{rain} is the total rainfall.

Thus for 2.54 cm of rain,

$$h_L = 2.54 / (0.25 \times 0.25)$$
$$= 40.64 \text{ cm (16 in)}.$$

For the drain located at the water table,

$$h_L^2 - H^2 = \frac{R}{k} \left[L \ (L-2\alpha_1 H) \right] \qquad \ldots \ldots (3)$$

If the impermeable layer is located just below the drain periphery, it may be assumed that $H \simeq 0$ and equation (3) degenerates to

$$h_L^2 = \frac{R}{k} \ L^2 \qquad \ldots \ldots (6)$$

$$\text{or} \quad L = \sqrt{h_L^2 \ \frac{k}{R}} \qquad \ldots \ldots (7)$$

If the average rainfall rate is 0.391 cm/hr or 0.00651 cm/min (0.00256 in/min), the actual amount infiltrating the soil is lower due to runoff and storage depression, interception and evaporation. Therefore, assuming the following set of conditions for this example;

Runoff and Storage Depression	21%
Interception	3%
Evaporation	1%
Deep Seepage	1%
Total	26%

Thus 26% of the rain will not reach the weeping tile. The average rainfall rate reaching the tile may then be taken as

$$R = 0.00651 \text{ cm/min} \times 0.74$$
$$= 0.00482 \text{ cm/min} \quad (0.0019 \text{ in/min})$$

$$\therefore \quad L = \frac{40.64^2 \times 0.1741}{0.00482}$$

2.442 m (8.01 ft).

This is the distance influenced by the weeping tile.

4.5 Volume of Rain Drained by Weeping Tile

For the calculation of property area influenced by the drain, the corner areas are neglected and if the distance between houses is less than the calculated 2L, the actual distance divided by 2 is used.

For the example of the Niagara Falls house, we will assume all the houses on the street are identical in property size, house, and driveway dimensions. From Figure 6, both front and back lawns have dimensions greater than 4.88 meters. The distance between the houses is only 4.27 meters (14 ft.) whereas 2 L = 4.88 m; therefore, L should be set at 2.13 m (7 ft.)

$$\therefore \quad \text{Total Rainfall area} = 2.13 \times (14.12 + 13.56) + 2.44$$
$$\times (7.93 + 7.93 + 1.47)$$
$$= 59.04 + 42.29$$
$$= 101.3 \text{ m}^2 \ (1090 \text{ ft}^2)$$

$\therefore$ Rain Volume = 2.54 cm x 0.74 x 0.01 $\frac{m}{cm}$ x 101.3m^2

= 1.904 m^3 (419 Igal)

Therefore, the rain falling on the ground contributed 1.904 m^3 to the tile. The other contribution to weeping tile flow comes from the roof eavestrough. Figure 6 shows three downspouts from the eavestroughs one which is buried 60.96 cm (2 ft.) into the ground, and the others discharging into small ditches leading away from the house. It is assumed that 80% of the flow from the buried spout contributes to the tile, while only 40%, or possibly less, from the other spouts contribute to the weeping tile.

$\therefore$ Total Roof Flow = 105.91 m^2 x 2.54 x 0.01 $\frac{m}{cm}$ = 2.69 m^3

or 2690 l.

Assuming the three downspouts divide the flow equally, the infiltration volume reaching the tile will be

V_{roof} = 2690 (80% (1/3) + 40% (2/3)

= 2690 x 0.533 = 1434.67 l (315.83 Igal)

The total weeping tile flow is 1904 l + 1434.7 l

= 3338.7 I (734.99 Igal)

Thus, a value of 3,339 l should flow as a result of this rain from the roof and from seepage through the soil.

4.6   Calculation of L if Impermeable Barrier is Below Drain (H>0).

For the purpose of comparison, the situation in which the impermeable barrier is some distance below the weeping tile, as illustrated in Figure 1, is examined and the value of L

determined from equation (3). Using h_L = 40.64 cm, R = 0.00482 cm/min and k = 0.1741 cm/min, as below, and assume H, the distance from the weeping tile to the impermeable barrier is 50.0 cm (19.7 in). If the tile radius, δ is 5.08 cm (2 in),

$$\frac{\delta}{H} = \frac{5.08}{50} = 0.1016$$

$$\alpha_1 = \frac{1}{\pi} \ln \left[2 \left(\cosh \frac{\pi\delta}{H} - 1 \right) \right]$$

$$= \frac{1}{\pi} \ln \left[2 \left(\cosh \frac{\pi \times 5.08}{50} - 1 \right) \right]$$

$$\cosh \frac{\pi \times 0.1016}{50} = 1.052$$

$$\therefore \quad \alpha_1 = -0.7205$$

$$\therefore \quad (50.0 + 40.64)^2 - 50.0^2 = \frac{0.00482}{0.1741} \quad L \ (L + 2 \times 0.7205 \times 50.0)$$

$$\text{or} \quad 5715.6 = 0.02763 \ (L^2 + 72.05L)$$

$$\therefore \quad L^2 + 72.05L - 2.069 \times 10^5 = 0$$

$$\therefore \quad L = 420 \text{ cm } (13.78 \text{ ft})$$

Thus the distance influenced by the tile is 4.2 cm as compared to 2.4 m when H = 0. This is an increase of 75% resulting from an increase of 123% in the water table depth due to the impermeable barrier being located 50.0 cm below the drain.

4.7 Drainage Time

The time to drain the water table from a maximum height, h_L, to the drain level is calculated from Figure 4.

If it is desired that, q, the drain discharge rate is zero, then qL/kDH = 0. For m = 1, s' = 0.08.

$$\frac{kDt}{s'L^2} = 2.0$$

L' = 2 x L = 2 x 244.2 = 488.4 cm

$$\therefore t = \frac{2 \times 0.08 \times 488.4^2}{0.1741 \times 40.64}$$

= 5394.1 min or 89.9 hrs.

For the case where H>0, m = $\frac{H'}{D}$ = $\frac{40.64}{90.64}$ = 0.45, and

$$\frac{kDt}{s'L'^2} = 0.7$$

L' = 2 x 420 = 840 cm

$$\therefore t = \frac{0.7 \times 0.08 \times 840}{0.1741 \times 90.64}$$

= 2503.96 min or 41.7 hrs.

Thus shorter drainage times will result when the impermeable barrier is below the tile level.

Nomenclature

A	area perpendicular to flow, L^2
C	runoff coefficient
D	height of water table above impermeable barrier, L
d	effective particle diameter, L
H	hydraulic head difference, L and drawdown height, L
h_c	capillary rise, L, and capillary head at wetting front, L
h_L	height of water table at distance, "L", L
h_o	water depth on soil surface, L
h_T	head loss in transmission zone, L
h_w	pressure potential loss in the wetting zone, L
h	maximum water table rise, L
i	rainfall intensity, in/hr
k	permeability, darcys; and hydraulic conductivity, L/t
k_T	conductivity in the transmission zone, cm/min
L	distance in direction of flow, L
L'	value of 2L
n	porosity
Q	flowrate, L^3/t
Q_{rep}	replenishment rate, L^3/t
Q_{precip}	precipitation rate, L^3/t
Q_{inter}	interception rate, L^3/t
Q_{deep}	deep seepage rate, L^3/t
Q_r	runoff rate, L^3/t
Q_e	the evapotranspiration rate, L^3/t
R	rainfall intensity, cm/min
s	increment of saturation
s'	storage coefficient

t   time, t

y   y-coordinate, length of wetting from soil surface

      to wetting front.

y_o condition for drain located at the water table, L

Greek Letters

α_1 defined by equation (4)

α_2 defined by equation (6)

δ drain radius, L